Performance enhancement in cellular networks with dynamic cell sizing

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Abstract

This paper investigates the potential capacity improvements made possible through the use of dynamic cell sizing in a cellular network. The purpose of dynamic cell sizing is to reduce cell radii and thus enable in-cell users to increase their transmit powers. The use of higher transmit powers suppresses intercell interference and leads to an overall increase in capacity. This paper discusses the degree of capacity enhancement that can be achieved in this manner. The analysis indicates that the capacity of a single cell can be increased by as much as 38%. However, under uniform traffic conditions, this results in a ratio of supported-to-offered traffic of just 0.2, which is clearly unsatisfactory. Dynamic cell sizing performs significantly better in hot-spot conditions, where the in-cell traffic follows a normal distribution with the highest density in close proximity to the basestation. The ratio of supported-to-offered traffic under these conditions was found to rise to 0.6 to 1.0 depending on the traffic standard deviation and the location of the hot spot.

I Introduction

The deployment of first and second-generation cellular systems has involved extensive planning, both to achieve continuous RF coverage and to ensure the provision of capacity in the right locations. The process has been a costly one, counting for as much as 50-70% of the total network cost. With the explosive growth in the number of cellular subscribers, operators are now struggling to meet demand. Call blockage during the peak traffic hour has become an increasingly common occurrence. The operators can accommodate this increase in traffic by either adding more carriers to existing cell-sites, or by splitting the cell into several smaller cells. Both methods require the operator to derive a new frequency plan. Additionally, if cell splitting is performed, a new coverage plan will be required to ensure intercell interference is kept to a minimum. The cost of installing new hardware (transceivers and basestations) and devising new frequency and coverage plans is considerable. It is therefore vital for an operator to ensure that their resources (both hardware and spectrum) are utilised to their full potential. A model derived from real traffic measurements in the San Francisco Bay Area suggests that the ratio of traffic demand in the busiest hour to the quietest hour is almost 20 to 1 [1]. From an operators point of view it would be far more beneficial if the demand for service were more evenly distributed throughout the day. An even distribution would ensure a much higher utilisation of their infrastructure. Obviously it is not easy to influence user behaviour, however it is possible to engineer a more flexible network.

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In light of the above, it is of interest to investigate the potential benefits of dynamically controlling the size of any given cell within a layer of hierarchical cells. There are three main advantages to this approach. Firstly by dynamically controlling the cell size, ***flexibility*** is brought into the network. Secondly, basestations can now effectively borrow neighbouring resources as and when required. Finally, increasing or reducing cell sizes will also provide a potential *capacity* gain as well as enabling the network to modify its *coverage* area at any given time for optimum performance.

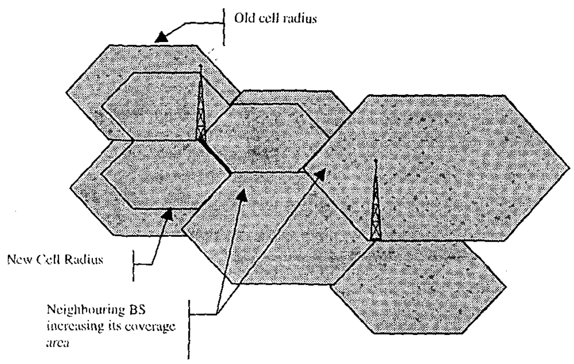

Figure 1: Cell radius reduction

II Dynamic cell sizing

In essence, dynamic cell sizing involves an increase or decrease in cell size to obtain a network performance advantage. Figure 1 illustrates how two neighbouring cells can interact with one another when one cell reduces its cell radius. Ideally the neighbouring cell will be able to increase its coverage area to prevent the creation of a gap in network coverage (alternatively an umbrella cell could be installed to cover the creation of such gaps). The interaction between cells will require sectorised basestation antennas that can increase or decrease their coverage area in any one sector. In this paper, the interaction between cells is not discussed any further and the work will concentrate on factors that influence the capacity of the cell. However, before this investigation can proceed, it is necessary to establish the theoretical limits of the system. These limits are discussed in the following section.

III CDMA uplink capacity

The E_b/N_0 for the i-*th* user in a cellular CDMA network (received at a power p_i, with m intracell and n intercell interferers engaged in a service with a channel rate BR with an activity factor of α, spreading bandwidth BW and thermal noise n_{th}) can be expressed as:

$$\left(\frac{E_b}{N_0}\right)_i = \frac{p_i}{\left(\sum_{\substack{k=1\\k\neq i}}^{N} p_k + \sum_{l=1}^{M} q_l\right)\cdot\alpha + n_{th}} \cdot \frac{BW_{ss}}{BR} \quad (1)$$

Assuming that all users in the same cell are received at the same power level, p, the above expression can now be rearranged as shown below:

$$\frac{E_b}{N_0} = \frac{1}{(N-1)\cdot\alpha + \frac{q_{tot}\cdot\alpha}{p} + \frac{n_{th}}{p}} \cdot \gamma \quad (2)$$

Solving for N yields:

$$N = 1 + \left(\frac{\gamma}{E_b/N_0} - \frac{q_{tot}\cdot\alpha}{p} - \frac{n_{th}}{p}\right)\Big/\alpha \quad (3)$$

where γ represents the processing gain (BW/BR), q_{tot} the total intercell interference and N the total number of users in the cell. As observed from equation (3), the capacity of a given cell in the network depends on the processing gain γ, the required ratio of energy per bit to noise power density, *Eb/No*, the total interference from other cells, the thermal noise and the voice activity. The interference, q_{tot}, received from other cells will effectively reduce the capacity with a given number of users. In a CDMA system it is well documented that if the intracell interference is 100%, then each of the cells in the first tier of interferers contributes 6% of interference [2]. With 6 cells in the first tier, the total interference becomes 136%. Normalising the interference (36/136) reveals that the intercell interference contributes 27% of the interference. The capacity of the single cell is reduced accordingly to 0.73 of its original value when deployed in a network.

The purpose of this investigation is to determine whether capacity can be improved by dynamically adjusting the cell size. From equation (3) it is evident that the capacity of a given cell would increase if it were possible to reduce the impact of the intercell interference. There are two available options to achieve this. Either the transmit power of all users in a cell is increased, or alternatively a method is found to suppress the interference from other cells. In the next section, a strategy based on the first of these ideas (i.e. home users increasing their transmit power) will be investigated in detail.

III.I Increasing the capacity by optimising the cell size

An initial investigation was performed by simulating traffic in a single cell, assuming interference contributions from neighbouring cells remains constant at 0.27 of their own interference [3]. The simulation parameters are given in Table 1.

The target received power level is normally set at a level equal to the thermal noise experienced in the given bandwidth so that the capacity is effectively reduced by 1 user. The reason for this is if the received power is too low, then the thermal noise becomes dominant and consumes unnecessary capacity. If it is too high, the intercell interference becomes unacceptable. The thermal noise in this instance is −174 dBm/Hz plus an additional 5 dB amplifier noise figure. For a 5 MHz bandwidth this yields 102 dBm.

Parameter	Value
Chipping rate	3.84 Mcps
Data rate	8.0 kbps
Channel rate	15 kbps
Voice activity	0.5
E_b/N_0	4 dB (magnitude 2.51)
Pathloss model	Dual slope, -2, -4, 100 m
Shadowing	0 and 8 dB
Power control error	0 - 1 dB
Target Rx power	-100 dBm
Minimum cell radius	200 meters
Maximum cell radius	500 meters

Table 1: Simulation parameters

Received power is then set to a slightly higher value than this, namely -100 dBm. Substituting the numbers from Table 1 into equation 2 (assuming there is no intercell interference), the capacity of the cell can be found to equal 204 users. Accounting for the intercell interference, the theoretical capacity for the cell is reduced to 148 users. To enable a single cell to accommodate more users, each user in the cell must be received at a higher power level. However, to avoid introducing more interference to the surrounding cells, the average pathloss from the home cells to the users must also be reduced. This effectively means that the cell radius will be shrinked, dropping users at the cell border to accommodate more users closer to the basestation.

III.II Increasing the received power

The initial investigation aims to discover how much the received power for each user must be increased to provide a given gain in capacity. The results are shown in Figure 2, assuming the external interference remains constant. As one would expect, the results clearly demonstrate capacity is gained by increasing the received power. An increment of 2 dB in received power would potentially enable the cell to support an additional 20 users. Increasing the power to −90 dBm enables the cell to support almost 200 users, very close to the upper theoretical limit of 204 users.

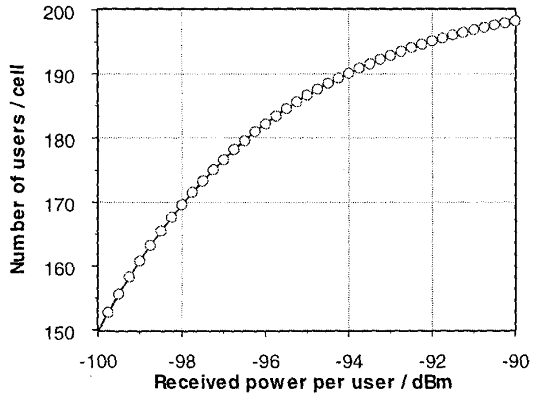

Figure 2: Increase in received power

The next step is to ensure that this increment in received power does not cause the surrounding basestations to experience an increased level of interference. This can only be achieved if the average user transmit power remains constant. The pathloss reduction can be accomplished through a reduction in the cell radius. The effect on the total user transmit power when the cell radius is reduced is shown in Figure 3.

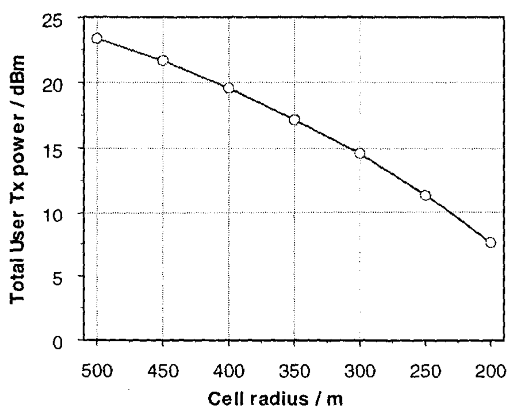

Figure 3: Reduction in total transmit power

The number of users remains the same for all radii. The results show that reducing the radius significantly decreases the total required transmit power and in this scenario, this will enable the transmit power to be increased accordingly to support more users. By reducing the maximum allowable pathloss and keeping the total user transmit power constant, it is possible for the cell to support more users without introducing additional interference to the surrounding cells.

However, the interference contribution to any of the surrounding cells will vary in accordance with the distribution of the users in the cell at any given instance in time. Assuming the users are uniformly distributed, there is a finite probability that all the users are located in one half of the cell's coverage area. This will significantly increase the interference experienced by cells on that side of the cell (and similarly reduce it for the others). Simulations were performed to investigate the variation in the received interference levels by the six surrounding cells, both with and without a shadowing component on the pathloss.

Shadowing:	0 dB	8 dB
Mean Rx power	-96.3 dBm	-82.4 dBm
Standard dev	4.70 dB	5.15 dB

Table 2: Received interference at the neighbouring basestation

The average received power is shown in Table 2. As expected, there is some variation in the received interference between the six surrounding cells. The average received power level is significantly influenced by the amount of shadowing assumed. However, the standard deviation of the received power for both 0 and 8 dB shadowing reveals only a minor difference. The standard deviation is approximately 5 dB, which represents a significant variation. However, in a real scenario, the surrounding cells will also receive interference from their neighbouring cells. This will tend to average out the large variations in received interference from any neighbouring cell.

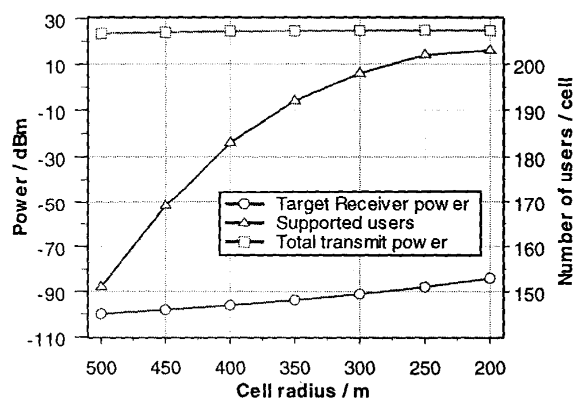

Figure 4: Impact of cell size on capacity

As can be observed from *Figure 4* the capacity increase was obtained through the reduction of the cell radius and an increase in the received power for each user. The total user transmit power remains constant, which means that the interference introduced into neighbouring cells is not affected by the increased number of users in the centre cell. By reducing the cell radius from 500 meters to 200 meters, the capacity of the cell has been increased by 33 %.

III.III User distribution in the cell

So far, only the theoretical capacity gain achieved through dynamic cell sizing has been discussed. The question of whether it is feasible to implement such techniques within in a cellular network remains open.

The analysis from the previous sections assumed that the users were uniformly distributed in the cell's coverage area. If the user distribution is to remain uniform, the density of the users must also increase to enable the basestation to support more users by reducing its cell radius. Figure 5 illustrates the relationship between the number of users which is supported in the cell when the cell radius is reduced from 500 to 200 meters (x-axis) and the total number of users in the original cell area, i.e. cell radius of 500 meters (y-axis).

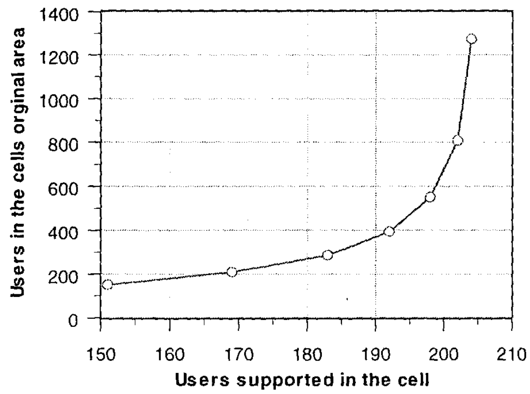

Figure 5: Total number of users in the cells original coverage area

Even for very small capacity improvements, the required user density rapidly becomes large. To achieve the maximum capacity there must be almost 1300 users in the cell's original coverage area. Clearly for traffic loads of that dimension, very little can be achieved with dynamic cell sizing. The only viable option for the operator is to split the cell's coverage area into several smaller cells. However, if the network has been planned so that the basestations are located in the centre of traffic hot spots, then the distribution of users may be approximated by a normal distribution with a given standard deviation. Figure 6 visualises the user density profile across the entire cell for a normal distribution with 1 standard deviation. It is assumed that the basestation is located at the point (x, y) = 0.

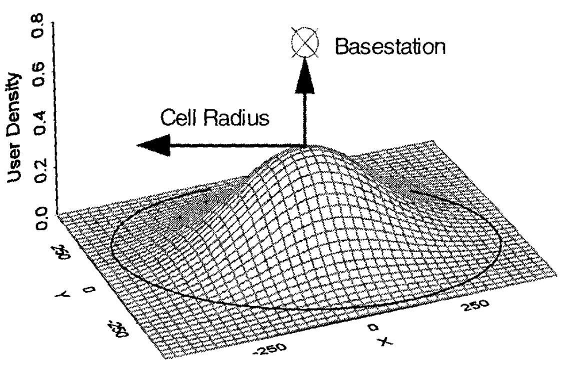

Figure 6: Normal distribution of users in the cell

The original cell radius (500 meters) reaches the equivalent position of 4 standard deviations of the standardised normal distribution, i.e. the 99.97% (virtually 100%) of the users are located within the original cell's area. To investigate the impact of both the distribution and the location of the hot-spot, the standard deviation and the mean was varied. The mean controls the location of the hot spot, whilst the standard deviation regulates the density of the distribution.

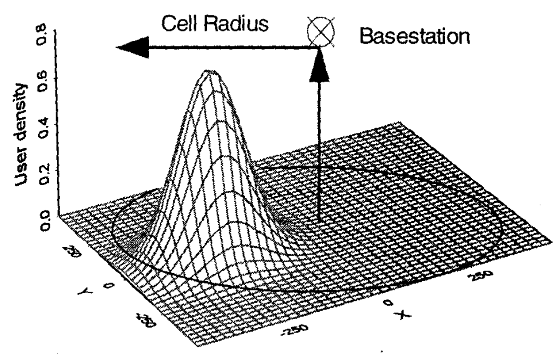

Figure 7: Normal distribution of users in the cell with mean of 2 and 0.5 standard deviation

This is illustrated in Figure 7 where the standard deviation is reduced to 0.5 and the mean is moved to 2 (which is equivalent to half the cell radius).

A number of simulations were performed to characterise the performance enhancement of dynamic cell sizing under non-uniform traffic conditions. The first set of results is shown in Figure 8 where the hot spot is assumed to be co-located with the basestation. The results show supported users normalised to the offered traffic according to the given distribution.

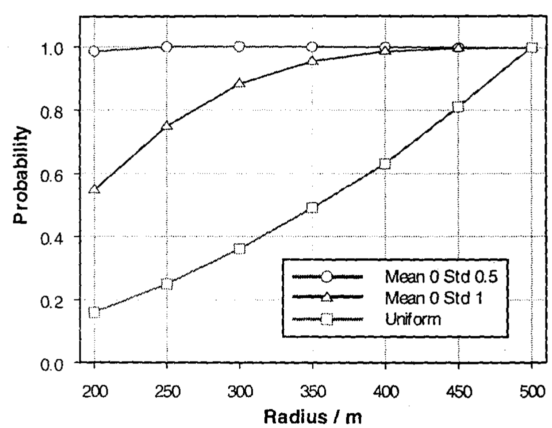

Figure 8: Fraction of supported users for varying Standard Deviations

It is evident from the graph that for uniform traffic at the minimum cell radius, the cell can accommodate less than 20% (0.2) of the offered traffic in the cell. However, the performance improves significantly if the traffic is normally distributed. For a standard deviation of 1, the basestation can always support more than 50% (0.5) of the offered traffic load. For smaller values of standard deviation, the performance improves further to close to 100% of load (0.5 standard deviation).

As the location of the hot spot within the cell is uncertain, an investigation was performed into how well dynamic cell sizing accommodated for the offered traffic load when the hot spot was placed somewhere other then the centre of the cell

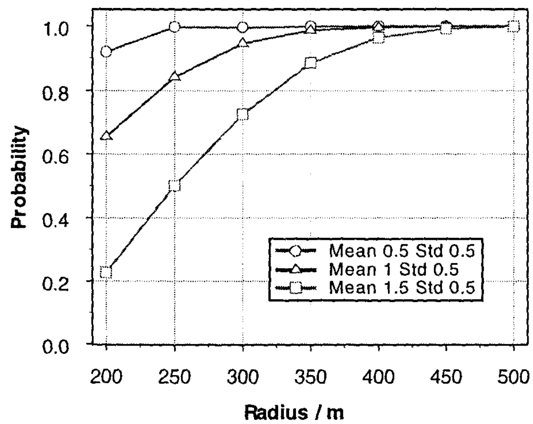

Figure 9: Fraction of supported users for varying mean

The results in Figure 9 show the performance when the hot spot is located 60 to 200 meters from the centre of the cell. The graphs illustrate that when the hot spot is located between 60 and 120 meters from the basestation, dynamic cell sizing is able to support 75% to almost 100% of the offered load. When the hot-spot is located further out then this (200 meters), the ratio of supported to offered traffic falls to approximately 50%, which still is significantly better than the performance in uniform traffic conditions.

IV Conclusions

This paper has discussed the possible benefits of implementing dynamic cell sizing in a cellular network. A CDMA network was utilised for the analysis. The purpose of dynamically adjusting the cell size was to increase the capacity of the cell in question. Extra capacity was obtained through increasing the target received power level. However, the average pathloss (and hence the cell radius) of the users was reduced accordingly to ensure that there was no increase in the interference experienced in neighbouring cells.

The results illustrated that under certain conditions it was possible to increase the capacity of a single cell by 38% while still not introducing extra interference (this was achieved by reducing the cell radius from 500 to 200 meters). However, to achieve this capacity improvement using a uniform traffic distribution, the cell is only able to supports 20% of the offered traffic (which is clearly unsatisfactory). Therefore, in uniform traffic conditions, dynamic cell sizing provides very little additional capacity. When the traffic load across the network is increased dramatically, the only option will be to deploy more basestations. On the other hand, when the traffic is normally distributed in the cell with the basestation positioned at the centre of the hot spot, the basestation is capable of supporting 50%-100% of the offered traffic load depending on the standard deviation of the distribution. This is clearly far more viable than the uniform traffic scenario. Dynamic cell sizing also performed well when the hot spot was not co-located with the basestation. When the location of the hot spot moved from 60 to 200 meters from the basestation, the performance varied from 50 to 95% of the offered traffic.

Results from this study show that dynamic cell sizing may have a useful part to play in future hierarchical cellular networks. Although the method cannot be used to significantly increase overall network capacity, it can be used to accommodate small fluctuations in local traffic levels. This enables the technique to reduce infrastructure requirements, particularly in areas with occasional hot spots.

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References

[1] D. Lam, D. C .Cox, and J. Widom, *Teletraffic Modelling for Personal Communications Services*, IEEE Communications Magazine, Vol. 35, No. 2, Feb 1997, pp. 79-87

[2] K. Gilhousen, I. Jacobs, R. Padovani, A. Viterbi, L. Weaver, C Wheatley, *On the Capacity of Cellular CDMA System*, IEEE Transactions on Vehicular Technology. Vol. 49, No 2, May 1991, pp. 303-312

[3] TIA TR45.5, *An overview of the Application of Code Division Multiple Access (CDMA) To Digital Cellular Systems and Personal Cellular Networks*, March 1992